Comparative Analysis of Traffic Accidents over Two Time Periods and Approach to Road Safety Management of Highway

Moe Thet Thet Aye[a], Kyaing[b]

[a,b] *Department of Civil Engineering, Yangon Technological University, Ministry of Science and Technology, Insein 11011, Yangon, Myanmar*
[a] *Email:* ***moethetthetaye@gmail.com***
[b] *Email:* ***kyaingkyaing63@gmail.com***

Abstract: Highway safety is essential to transportation engineering because of road accidents are an unavoidable and unpredictable feature of everyday life. Accidents are also caused by a wide range of other factors, either directly or indirectly. Finding hazardous areas where traffic accidents happen is essential for improving highway safety. The accident conditions on the Yangon-Bago Highway are compared in this study between two time periods, namely the first period (2009–2010) and the second period (2017–2018). This comparison aims to identify trends in accident frequency and severity, examining factors such as traffic volume, road conditions, and driver behavior during these periods. According to the study, there were three dangerous zones in first period and fifteen in second period. Understanding accident prone areas can help lower the number of traffic accidents and enhance road safety for all road users.
Keywords: Traffic Accidents, Highway Safety, Hazardous Zones.

1. INTRODUCTION

These days, road accidents are a global issue that have a significant negative impact on people, property, and society. Approximately 1.35 million individuals lose their lives in traffic accidents each year, and these accidents cost the majority of nations 3% of their GDP. Pedestrians, cyclists, and motorcyclists are the most vulnerable road users, accounting for almost half of all traffic fatalities. Therefore, it is essential to use effective measures to lower the number of traffic accidents. In Myanmar nowadays, transportation is essential for both passenger movement and the carrying of products and other items. Therefore, it's also essential that major highways, expressways, and other roads be properly planned and improved for the benefit of users. The choice of roadway location and geometric elements are the main concerns of highway design. One fundamental first stage in the planning of a new roadway is choosing its location. The geometric pattern will be properly implemented.

The goal of this literature review is to give a broad overview of road safety management systems, covering its key elements, roles, and decision-making procedures. Based on the available literature, it provides a simplified form of the literature review that was done early in the project to outline the framework and fundamental ideas of road safety management as well as to make reference to the data, knowledge, and tools that are required for this purpose. The results are concentrated on road safety management and the key elements that are linked to "good practice" in this area.

2. LITERATURE REVIEW

One of the leading causes of violent deaths worldwide is traffic accidents. Every day, a large number of individuals are killed or injured in road accidents, and the expense is excessive. Traffic accident analysis should be conducted to identify the dangerous locations on a road in order to reduce the frequency of traffic accidents. Traffic accidents are irregular and unpredictable. Nonetheless, road accidents have resulted in numerous fatalities and injuries worldwide. These outcomes can be caused by a variety of variables, the primary among them being reckless driving, a lack of infrastructure, the environment, the weather, etc. Driver behavior, vehicle safety, and roadway safety are the first three main facets of highway safety.

Roadway safety is a component of highway safety that is influenced by the physical characteristics of the road, including its design, signs, surface markings, operating conditions, roadside items (such utility poles, signs, trees, and guardrails), bridges, and intersections. Highway crashes have significant negative effects on communities, both psychologically and economically. Road safety management is the process of developing and implementing policies and programs to reduce the risk of road traffic injuries and fatalities. It also involves monitoring and evaluating the effectiveness of these programs. It is also a collaboration of all elements of the road system to minimize the chance of a crash.

3. METHODOLOGY

The purpose of this study is to suggest road safety management based on an evaluation of traffic accidents across two time periods as well as roadway and roadside safety assessment. In order to reduce traffic accidents and increase highway safety for all users, it is important to study accident analysis and the identification of accident prone locations.

3.1 Study Area

The highway that links between Yangon and Bago cities is considered as study area in this study. Yangon is the largest city in Myanmar and the industrial and commercial center of the country. Bago is also the capital city of Bago Division and it is one of the cities in Myanmar that connects country’s largest economic city Yangon, governmental capital Naypyitaw and second largest city Mandalay. These two major cities of Yangon and Bago are connected with this Yangon-Bago Highway and it is a main highway that links Upper Myanmar and Lower Myanmar of our country. The length of Yangon-Bago Highway is 32 miles 6 furlongs (52.7 km). The location of the study area is shown in following Figure 1.

Figure 1. Location of the Study Area

3.2 Data Collection and Methods of Analysis

The traffic accident data and statistics of Yangon-Bago Highway during two periods are collected from Myanmar Police Force. The traffic accident data which is caused on this highway during first period (from 2009 to 2010) and second period (from 2017 to 2018) are collected. These accident record data are collected from five police stations which are Bago No.1. No.2, No.3, Indakaw and Hlegue Police Stations. The more traffic flow on this highway, the more road traffic accidents happens. Therefore, the traffic volume data of these two periods are also collected from two toll gates such as Htauk Kyant and Bago toll gates. This highway is responsible with BOT system by Max Highway Company Limited. Therefore, traffic volume data of this highway are collected from this Company.

The implementation program of this study is shown in following Figure 2.

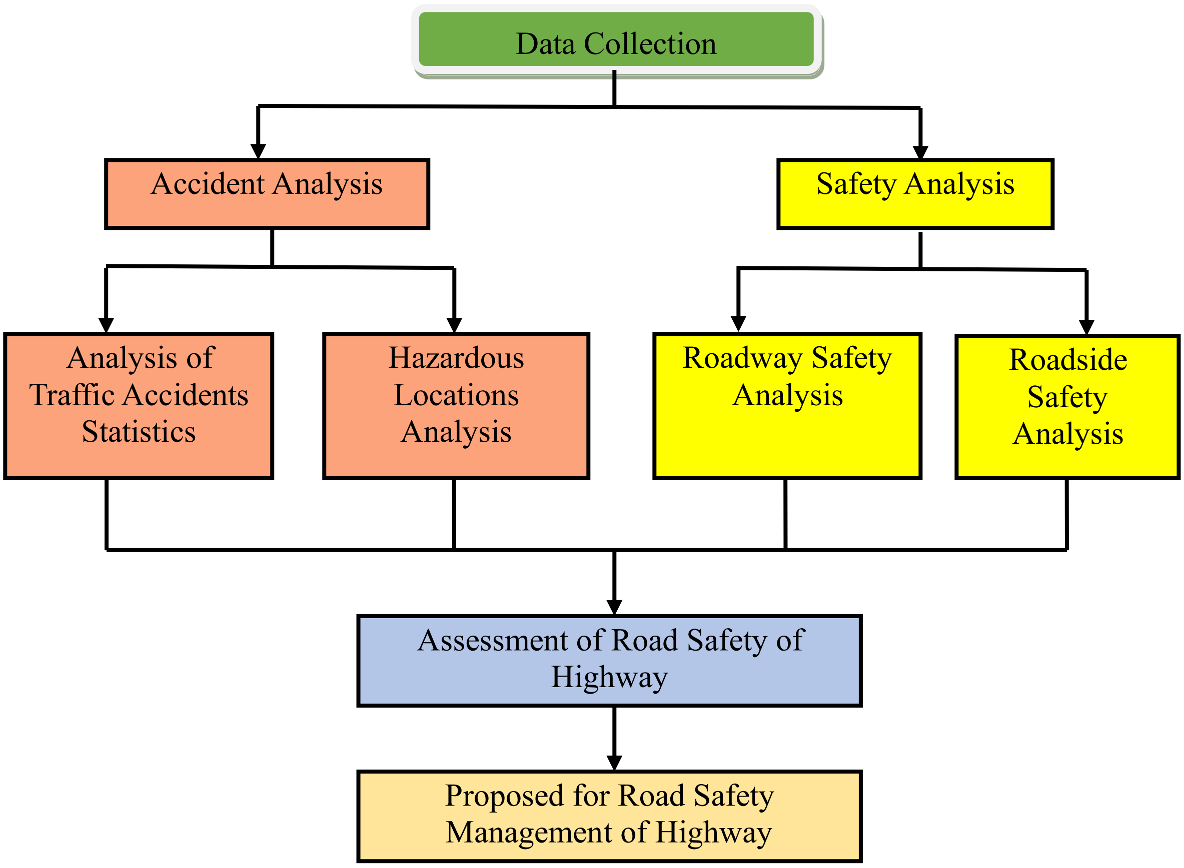

Figure 2. Implementation Program of Study

In this study, firstly, accident analysis is carried out and accident prone locations are then analyzed by frequency method, accident severity index method and Kernel density estimation (KDE) method to determine high hazardous zones along Yangon-Bago Highway. After the high hazardous zones are known, the assessment of highway accident and safety condition is also carried out and then, suitable remedial countermeasures for this hazardous zones with road safety management can be suggested to reduce accident rate and to improve highway safety.

3.2.1. Frequency Method

A number of statistical methods and models have been used to estimate accident rates and accident frequencies at a specific location over a given interval of time. Among these methods and models, frequency method is used in this study to identify and ranking of blackspot locations on the basis of the number of accidents. This method is commonly used to measure the safety for a dangerous location. Highway systems of 2,500 miles or less can generally adopt this method. In this study, the length of the selected highway is 32 miles 6 furlongs and therefore, this highway is adaptable with frequency method. There is no consideration given to exposure or accident severity.

3.2.2. Accident Severity Index Method

A number of statistical models have been used to estimate accident rates and/or accident frequencies at a specific location over a given interval of time. A site is considered to be dangerous when its priority value (P), calculated using the following formula, equals 15 or more:

$$P=X+3Y+5Z \tag{1}$$

Where, X = total number of light injuries
Y = total number of serious injuries
Z = total number of deadly injuries

3.2.3. Kernel Density Estimation Method

In this study, Kernel density estimation (KDE) method is used which is one of the most common methods for identifying hotspots for crime and crash, due to a smooth and continuous surface map of risk targets within the study area. Kernel density estimates the density of events around these points, scaled by the distance from the point to each event. The density of events is highest when the radius from the point is zero and the density decreases when the radius increases.

The primary benefit of the KDE approach over traditional statistical clustering techniques is that the kernel's bandwidth expresses the uncertainty regarding the precise location of a traffic accident, hence distributing the accident risk. To find the dangerous areas and accident trends, both simple and kernel density were used. In order to identify accident hot and cold spots, the clustering analysis has been examined in relation to accident categories and incidence times. The spatial analyst extension in this work uses the kernel density estimation approach to discover accident trends and dangerous spots on the Yangon-Bago Highway.

3.2.4. Crash Reduction Factor and Crash Modification Factor

A crash reduction factor (CRF) is the percentage of crash reduction that might be expected after implementing a given countermeasure at a specific site. A crash modification factor (CMF) is a multiplicative factor used to compute the expected number of crashes after implementing a given countermeasure at a specific site.

$$CMF=1-(CRF/100) \tag{2}$$

CMF is that CRF provides an estimate of the percentage reduction in crashes. CMF is a multiplicative factor used to compute the expected number of crashes after implementing a given improvement. It is important to note that a CMF represents the long-term expected reduction in crashes and this estimate is based on the crash experience at a limited number of study sites; the actual reduction may vary.

4. ANALYSIS AND RESULTS

The road condition of Yangon-Bago Highway between two nonconsecutive periods are not significantly changed. The road performance conditions of Yangon-Bago Highway are mentioned as follows:

Table 1. Road Condition of Yangon-Bago Highway

Design year, n	**20 years**
Design speed	The speed limit is 30 mph (48 km/h) within city boundaries and 50 mph (80 km/h) outside city limits.
Length of highway	32 miles 6 furlongs (52.7 km)
Right-of-way	100 ft
Number of traffic lanes	6 lanes
Width of travelled lane	12 ft
Width of pavement	72 ft
Width of shoulder	6 ft
Width of median	8 ft
Type of pavement	Bituminous
Type of highway	Multilane highway

4.1. Traffic Volume and Growth Rate between Two Periods

The traffic volume Yangon-Bago Highway's for two time periods is gathered from Htauk Kyant Toll and Bago Toll of Max Highway Company, which are in charge of the B.O.T system, and compared in this study.

Figure 3. Traffic Volume between Htauk Kyant Toll and Bago Toll

It was observed that the traffic volume at Htauk Kyant Toll significantly increased during the second period compared to the first period. Similarly, traffic volume at Bago Toll also rose in the second period. The increase in the number of vehicles may lead to a higher risk of traffic accidents on the highway.

The growth factor of traffic volume are calculated by Linear Growth formula to know the traffic volume development rate between two different years of the same highway. The traffic volume conditions between two toll gates located on this highway are described in Figure 3. Linear Growth increase in traffic volumes over time. This method assumes a constant amount of growth in each year and does not consider a capacity restraint.

$$\text{Future Volume} = GF \times \text{Base Year Volume} \tag{3}$$

Where:

$$GF = \text{Growth Factor} = 1 + (G \times N) \tag{4}$$

G = Linear annual growth rate, expressed as a decimal

N = Years beyond the base year

In this study, the forecast 7-year traffic volumes are developed based on historical counts. The traffic volume data between two toll gates that are located on this highway are described in figure 2. Based on these data, the 7-year growth factor would be 1.709. Assuming linear growth in the future, the annual growth rate would be (1.709–1.0)/7 = 0.1014, or 10.14%.

4.2. Accident Analysis between Two Periods

This research analyzes accident patterns on the Yangon-Bago Highway between first period (2009-2010) and second period (2017-2018), identifying critical trends and high-risk locations. The findings are crucial for policymakers and road safety engineers as they develop effective strategies to mitigate accidents and improve safety on the highway. The number of casualties, classified by severity, was collected along the highway. According to the traffic accident statistics and records, the breakdown of casualties by severity is presented in Table 2.

Table 2. Comparison of Crash Severity and Number of Casualties

Crash Severity	Number of Casualties (Persons)	
	2009-2010	2017-2018
Total Number of Crashes	112	234
Fatalities	25	41
Serious Injuries	86	98
Slight Injuries	93	105

4.2.1. Gender Distribution in Traffic Accidents

The gender-based distribution percentages among accidents on the Yangon-Bago Highway between two different time intervals is shown in the two pie charts. The risk profiles linked to various genders in traffic accidents are revealed by these charts, which also illustrate important demographic trends.

Figure 4. Percentage of Gender

The gender gap in accidents is much more noticeable in Figure 4. In both periods, males made up a surprising 79% and 82% of the total, while females accounted only 21% and 18%. The difference emphasizes how male drivers are more likely to suffer slight or serious or even fatal injuries in collisions.

4.2.2. Road Accidents by Type of Collision

In this study, the road accident data are based on two nonconsecutive periods of Yangon-Bago Highway. The total road accidents in Yangon-Bago Highway are categorized into six main groups as shown in Figure 5.

Figure 5. Comparison of Accident Frequency Distribution by Types of Collision

The above Figure 5 shows the road accidents by type of collision that occurred along Yangon-Bago Highway. Along this highway, there were 112 accidents in the first period and 234 in the second period. Collisions with other motor vehicles on the roadway were determined to be the primary cause of the greatest percentage of injuries, accounting for 32 percent and 46 percent for both periods. Driver fatigue, careless driving, reckless overtaking, and excessive speeding are the causes of this. Therefore, it is recommended that drivers slow down, particularly in busy areas, and pay attention to warning signs and traffic signs. Drivers must abide by traffic restrictions, especially when it comes to preventing accidents on highways.

4.2.3. Vehicle Involvement

The Figure 6 represents the involvement of vehicles in accidents along Yangon-Bago Highway.

Figure 6. Frequency of Vehicle Types on Accidents in Two Different Periods

It is observed that the motorcars and motorcycles are the most involved vehicles in accidents on Yangon-Bago Highway on both periods. This can be the factor that most of the local people use second-hand cars and they have no or less safety features for vehicle users. The motorcycle is the most popular mode of transport especially in rural areas. To reduce the severity of motorcycle accidents, the motorcyclists should wear the helmet whenever they drive motorcycles and they should follow the law enforcement exactly. To get more safety, the motorcycles entering on the highway should be enforced the helmet law along Yangon-Bago Highway.

4.2.4. Time of Accidents in Yangon-Bago Highway

Road accidents in Yangon-Bago Highway are studied and analyzed in terms of hour and month according to the time of accident occurring. The number of accidents caused by different times is needed to study in Yangon-Bago Highway. Firstly, the occurring time of accidents are studied in term of hour. This investigation helps to know the highest accident time can be occurred. Figure 7 shows accidents in different time periods. 24 hours can be divided into day time and night time in every three hours.

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Figure 7. Comparison of Accident during Different Time Intervals (in terms of hour)

Through the above Figure 7, it is observed that the accidents which occurred during the night is more than accidents which occurred during the day in both periods. This is due to the fact of drinking alcohol by drivers, high speed, drowsiness and the weakness of highway lighting at nighttime.

Figure 8. Accident Distribution during Different Time Intervals (in terms of month)

Figure 8 shows the accidents that occurred in different month of Yangon-Bago Highway in two periods (2009-2010 and 2017-2018). It is observed that June with 13 percent became the black month in first period and 12 percent in second period on Yangon-Bago Highway.

4.3. Identification of High Hazardous Zones by Frequency Method

The frequency of accidents along Yangon-Bago Highway during first period (2009-2010) and second period (2017-2018) are shown in following Table 3. In this study, frequency method is used to analyze the traffic accidents. It is suitable to use for ranking the accident locations on this highway according to the data information. It is denoted 0.5 miles (4 Furlongs) interval as each zone and the zones are notified as Z. According to the frequency of traffic accidents, the dangerous locations on the highway of both periods can be ranked and studied.

Table 3. Frequency of the Accidents in Two Time Intervals

Zone No. (Z)	Miles		Frequency (2009-2010)	Frequency (2017-2018)	Total Frequency	Rank
	From	To				
1	1	1.5	0	4	4	13
2	1.5	2	0	1	1	16
3	2	2.5	2	0	2	15
4	2.5	3	3	8	11	6
5	3	3.5	0	0	0	17
6	3.5	4	3	2	5	12
7	4	4.5	0	6	6	11
8	4.5	5	2	2	4	13
9	5	5.5	1	1	2	15
10	5.5	6	3	1	4	13
11	6	6.5	2	2	4	13
12	6.5	7	3	6	9	8

13	7	7.5	5	5	10	7
14	7.5	8	4	2	6	11
15	8	8.5	4	2	6	11
16	8.5	9	0	0	0	17
17	9	9.5	3	3	6	11
18	9.5	10	0	0	0	17
19	10	10.5	0	0	0	17
20	10.5	11	1	2	3	14
21	11	11.5	2	2	4	13
22	11.5	12	1	0	1	16
23	12	12.5	0	0	0	17
24	12.5	13	2	1	3	14
25	13	13.5	1	2	3	14
26	13.5	14	2	0	2	15
27	14	14.75	3	9	12	5
Mile Post changes suddenly from 14 Miles 6 Furlongs to 31 Mile due to entering of No.2 Main Road comes in this intersection (Za Yat Kwin Intersection)						
28	31	31.5	0	0	0	17
29	31.5	32	3	4	7	10
30	32	32.5	0	2	2	15
31	32.5	33	1	4	5	12
32	33	33.5	2	6	8	9
33	33.5	34	1	10	11	6
34	34	34.5	1	4	5	12
35	34.5	35	0	3	3	14
36	35	35.5	1	4	5	12
37	35.5	36	2	12	14	4
38	36	36.5	1	7	8	9
39	36.5	37	0	0	0	17
40	37	37.5	1	3	4	13
41	37.5	38	2	2	4	13
42	38	38.5	0	2	2	15
43	38.5	39	0	2	2	15
44	39	39.5	2	2	4	13
45	39.5	40	0	0	0	17
46	40	40.5	0	3	3	14
47	40.5	41	1	2	3	14
48	41	41.5	2	1	3	14
49	41.5	42	0	0	0	17
50	42	42.5	0	2	2	15
51	42.5	43	2	7	9	8
52	43	43.5	3	5	8	9
53	43.5	44	2	2	4	13
54	44	44.5	0	6	6	11
55	44.5	45	4	7	11	6

56	45	45.5	2	8	10	7
57	45.5	46	1	1	2	15
58	46	46.5	0	1	1	16
59	46.5	47	1	2	3	14
60	47	47.5	3	7	10	7
61	47.5	48	0	6	6	11
62	48	48.5	3	12	15	3
63	48.5	49	7	15	22	1
64	49	49.5	9	13	22	1
65	49.5	50	8	8	16	2

4.4. Identification of High Hazardous Zones by Accident Severity Index Method

Each zone is divided into 0.5 miles interval. To get their priority values of each zone in Yangon-Bago Highway, the numbers of minor injuries, numbers of major injuries and numbers of fatalities in this highway during two time intervals are collected from Myanmar Police Force. The priority value of each zone is calculated by using Equation 1. The priority values of each zone during two periods are shown in the following Figure 9 and 10.

Figure 9. Priority Values of Each Zone (2009-2010)

Figure 10. Priority Values of Each Zone (2017-2018)

In this study, there are 65 zones on this highway and mile post changes suddenly from 14.75 miles to 31 miles between zone 27 and 28. This is because of the addition of the length of No.2 Main Road. If the priority value based on the Severity Index Method is greater than 15, this zones can be classified as high hazardous zone or black spot of highway. Through this table, Zone 63, 64 and 65 should be considered as high hazardous zones during first period. Moreover, Zone 1, 7, 12, 27, 33, 37, 38, 51, 54, 56, 60, 61, 62, 63 and 64 are also considered as high hazardous zones during second period since they have priority values are greater than 15. The number of hazardous zones in second period (2017-2018) are significantly more than first period (2009-2010). This is the primary factor of increase in motorization on the highway year by year can cause the road accidents more and more. Therefore, the number of hazardous zones in second period are more than in first period.

4.5. Accident Severity Index

The accident severity index measures the number of deaths per accident. The accident severity index on Yangon-Bago highway road during two time periods is calculated as follows and the results are shown in table 4.

$$\text{Severity Index, SI} = \frac{\text{the number of fatalities}}{\text{the number of accidents}} \quad (3)$$

The following Table 4 shows the two severity index values between two periods. Although the number of accident in first period is decreased than in second period, but the fatality rates in first period are increased than second period. Therefore, it is found that the severity index value in 2009-2010 is greater than in 2017-2018.

Table 4. Comparison of Severity Index Values

Interval of Time	Severity Index
First Time Interval (2009-2010)	0.223
Second Time Interval (2017-2018)	0.175

4.6. Clustering of Blackspots for Yangon-Bago Highway

Figure 11 shows the results of hotspot clustering approach for these highway are based on the traffic accident data for two periods.

Figure 11. Accident Locations Mapping on Yangon-Bago Highway with Kernel Density Estimation Method

The findings of hotspot locations were shown in this analysis that there is not just one case at each location and shown on the map in red speckles for both lanes of the highway. Considering the Figure 11, the most dangerous positions are practically found on the Yangon-Bago Highway. It is noticed that there are three dangerous sections spread which is the most dangerous portion of this highway. The red colour represents the very high accident occurring location and the orange colour shows the high accident occurring location. The yellow colour represents the medium accident occurring location and the green colour shows the low accident occurring location. The blue colour demonstrates the location which has not occurred. Along this highway, the first dangerous section are found at Zone 1, 4, 7, 12 and 13 and the second dangerous section are observed at Zone 27, 32, 33 and 37. Moreover, it is discovered that Zone 54, 55. 56, 62, 63, 64 and 65 are located in the third dangerous section on the Yangon-Bago highway. The blackspot locations are shown in following Table 5.

Table 5. Blackspots Location Analysis

Zone No. (Z)	Location Analysis (Straight or Curve)	Remark
1	Straight Portion	
4	Straight Portion	
7	Straight Portion	
12	Straight Portion	
13	Straight Portion	
27	Straight Portion	Intersection
33	Straight Portion	
37	Curve Portion	
38	Straight Portion	
51	Curve Portion	
54	Straight Portion	
55	Straight Portion	
56	Curve Portion	
60	Straight Portion	
61	Straight Portion	
62	Curve Portion	
63	Curve Portion	
64	Curve Portion	
65	Straight Portion	

4.7. Factors affecting the Road Safety Problems

Road traffic crashes are primarily caused by a combination of vehicle-related factors, road infrastructure issues, and road user behavior. It is essential to view these causes as part of an interconnected system. The interaction between physical infrastructure and human users plays a critical role. Road and vehicle designs must accommodate human error to ensure safety. On the Yangon-Bago Highway, various contributing factors have led to a high rate of road traffic accidents. Many drivers travel at speeds exceeding the legal limit and frequently disregard traffic regulations. Additionally, pedestrians, motorcyclists, and users of slow-moving vehicles often behave carelessly, showing little regard for traffic laws.

To reduce the accident rate and enhance safety on the Yangon-Bago Highway, driver behavior, pedestrian and motorcyclist awareness, road infrastructure improvements, vehicle conditions, law enforcement should be carefully considered. By addressing these factors systematically and holistically, the risk of road crashes can be significantly reduced.

Table 6. Factors affecting Road Accidents

Factors that causes Road Accidents	Road Safety Remedial Measures	Photos
Insufficient guardrail protection	Crash-tested guardrails should be installed at appropriate intervals, especially near bridges.	
Lack of retroreflective signposts impairs night visibility.	Retroreflective traffic signs and road surface markings should be installed and maintained regularly to ensure night-time visibility.	
Vulnerable road users on the highway	Targeted education and awareness programs should be implemented for vulnerable road users.	
Lack of road shoulders reduces recovery space for vehicles and increases crash risk.	Continuous and adequately wide roadside shoulders should be constructed to enhance safety and accommodate emergencies.	
Missing pavement markings reduce lane visibility and guidance, especially at night or in poor weather.	High-visibility, durable pavement markings should be applied consistently along the highway	
Active construction sites near the roadway pose collision risks.	Appropriate safety barriers and signage should be installed around construction zones.	

4.8. Selection of Countermeasures and their CRFs for Blackspots

The following countermeasures are selected and proposed for accident blackspots or hazardous zones of Yangon-Bago Highway to reduce traffic accidents. Their crash reduction factors (CRF) and their treatment life in years based on Countermeasure Service Life Guide of Federal Highway Administration, are also shown in this Table 7.

Table 7. Types of Selected Countermeasures and Their CRFs

Code (C)	Types of Countermeasures	CRF for All Casualty Crashes (%)	Treatment Life(Year)
1	Install modular crash attenuators (CAMS) with appropriate regulatory and warning signs.	15% Motorcycles crashes only	10
2	Install fixed speed and red-light enforcement cameras in both urban and rural areas.	30% Speed related Crashes	10
3	Upgrade existing roadway lighting to improve night-time visibility and safety.	35% Dark Crashes only	15
4	Install enhanced lighting at pedestrian crossings to increase visibility for both drivers and pedestrians.	30% Pedestrian crashes	15
5	Install advance curve warning signs to alert drivers of upcoming bends.	40%	15
6	Widen rural roadways by adding passing or climbing lanes to improve traffic flow and safety	• 35% (if there is No increase in operating speed) • 30% Run off road crashes • 14% FSI crashes	20
7	Expand urban roadways with additional lanes where capacity or safety improvements are needed	30% (if there is No increase in operating speed)	20
8	Install new traffic signal systems at high-conflict or high-volume intersections.	45%	10
9	Install directional and informational guide signs for improved driver navigation.	15%	15
10	Install advance warning signs to alert drivers of upcoming road conditions or hazards.	15%	15

In order to decrease the accident rate in hazardous areas, the countermeasures which associated the causes of accidents in blackspots are determined and proposed in this research.

4.9. Predicted Effectiveness of Countermeasures based on Crash Reduction Factors

The types of countermeasures are selected based on the analysis of the causes of accidents in accident prone areas. The observed crashes frequency before treatment and expected average crash frequency after treatment based on crash reduction factors of countermeasures are predicted in the following Table 8.

Table 8. Average Crash Frequency in Blackspots before and after Treatments

Zone (Z)	Observed Crashes frequency before treatment	Types of Countermeasures	Expected average crash frequency after treatment
1	5	C1 ,C2, C3 , C9, C10	2
4	3	C1, C2, C3, C4, C10	1
7	5	C1, C2, C3, C4, C10	2
12	6	C1, C2, C3, C4, C10	3
13	5	C1, C2, C3, C4, C10	2
27	10	C5,C8, C9, C10	4
33	17	C1, C2, C3, C9, C10	9
38	8	C1, C2, C3, C9, C10	4
51	6	C1, C2, C3, C9, C10	3
54	6	C1, C2, C3, C9, C10	3
56	5	C1, C2, C3, C9, C10	2
60	11	C7, C9, C10	4
61	9	C7, C9, C10	4
62	11	C7, C9, C10	5
63	10	C7, C9, C10	4
64	7	C7, C9, C10	3
65	6	C7, C9, C10	2
66	8	C7, C9, C10	4
	Total = 130		Total = 61

4.10. Assessment of Highway Safety

The study analyzed road traffic crashes along the Yangon–Bago Highway during two nonconsecutive periods (2009–2010 and 2017–2018). In this study, 112 crashes were recorded during the first period and 234 crashes during the second period along the Yangon–Bago Highway corridor. The highest proportion of injury crashes, accounting for 32% and 46% respectively, were caused by collisions with other motor vehicles during both periods. Passenger cars and motorcycles were the most frequently involved vehicle types in crashes on the Yangon–Bago Highway in both periods. It was observed that traffic crashes were more likely to occur at night than during the daytime. Therefore, roadway lighting and traffic control devices such as speed limit signs, retroreflective signposts, and advance warning devices should be installed or upgraded, particularly at high-crash locations (also known as black spots), to reduce nighttime crash risk along the highway.

The frequency method was used for ranking the accident locations on this highway. According to the priority values of Accident Severity Index method, Zone 63, 64 and 65 were the high hazardous zones during 2009-2010. Moreover, Zone 1, 7, 12, 27, 33, 37, 38, 51, 54, 56, 60, 61, 62, 63 and 64 were also the high hazardous zones during 2017-2018. It was observed that there are three dangerous sections spread which is the most dangerous portion of this highway by clustering points of hotspots with Kernel density estimation method with QGIS. The first dangerous portion are located in Zone 4, 7, 12 and 13 and the second dangerous portion are observed in Zone 27, 32, 33, 37 and 38. Zone 51, 54, 55. 56, 60, 61, 62, 63, 64 and 65 were involved in the third dangerous portion on the Yangon-Bago Highway. It was observed that 13 blackspots are located mostly in straight portions of highway and 6 blackspots are located at curve portions of highway.

Accident data were analyzed by vehicle type, time (hour and month), types of vehicle collisions, and priority index. It was found that there were only three high-risk zones during the first period and fifteen high-risk zones along the Yangon–Bago Highway during the second period.

Based on this analysis, the following conclusions are drawn:

- With the increase in motorization, the number of traffic accidents has been rising each year, resulting in more accident blackspots.
- Accidents tend to occur more frequently in crowded areas, particularly involving vulnerable road users such as motorcyclists and drivers.
- The results indicate that Zone 64 (49–49.5 mile) was the most dangerous location during the first period, while Zone 33 (33.5–34 mile) was the most dangerous during the second period.
- Nighttime accidents outnumbered daytime accidents in both years. This may be attributed to drunk driving, driver fatigue, and speeding during nighttime hours.
- Motorcycles and motorcars were the vehicles most frequently involved in accidents in both years. Therefore, motorcyclists should be required to wear helmets and comply with traffic and helmet laws.
- Males were more frequently involved in road traffic accidents than females in both periods.

4.11. Road Safety Management for Yangon-Bago Highway

This study highlights the critical road safety challenges faced along the Yangon–Bago Highway, with particular attention to the spatial concentration of accidents and the behaviour of road users. The findings demonstrate that collisions, especially those involving motor vehicles and motorcycles, are heavily influenced by excessive speed, inadequate enforcement of traffic laws, geometric design weaknesses, and insufficient driver education.

To address these issues effectively, a multifaceted approach is required. Engineering improvements, including enhanced lighting and signage, must be paired with stricter law enforcement and sustained educational initiatives targeting all road users. Reducing speed limits in populated areas, enforcing helmet laws, and discouraging mobile phone use and drunk driving are essential actions to mitigate risks.

Ultimately, improving road safety on the Yangon–Bago Highway will depend on the coordinated efforts of transportation authorities, law enforcement agencies, and the general public. Through data-driven strategies and continuous monitoring, it is possible to reduce accident rates, save lives, and promote a safer and more sustainable transport system in Myanmar.

In populated urban areas and near construction sites, barriers or guardrails should be installed to protect vulnerable road users, including pedestrians and animals, from road traffic crashes. It was observed that accidents on the Yangon-Bago Highway during both study periods occurred slightly more frequently at night than during the daytime. Therefore, highway lighting, standard retroreflective signposts, and retroreflective guardrails should be installed along the highway to improve nighttime visibility. Additionally, countermeasures should be taken to address speeding and driving under the influence of alcohol.

Additionally, traffic control devices should be installed at necessary locations along the Yangon-Bago Highway. In the event of a road traffic accident, prehospital emergency care should be provided to the individuals involved. Therefore, ambulance services should be available in every township along the Yangon-Bago Highway. Emergency contact numbers and hotline information for ambulance services should be disseminated to all road users by the authorized road safety agencies.

The warning signs and educational posters should be clearly displayed at hazardous locations. High-quality road infrastructure and safe geometric design contribute significantly to the safety of road users. Therefore, a comprehensive road safety management system should be implemented along the Yangon-Bago Highway.

A total of 19 blackspots along the highway were analyzed based on their location characteristics. It was found that 13 blackspots are primarily located on straight sections of the highway, while 6 blackspots are situated on curved sections. Based on this blackspot analysis, the installation of warning signs to alert drivers to reduce speed on both straight and curved segments especially near intersections is recommended. Additionally, all drivers and road users must comply with traffic laws and regulations to enhance road safety.

In summary, the following road safety management measures for high-risk zones should be implemented for all road users:

- Seat Belt Use

The authorized road safety authorities should conduct public awareness campaigns to promote seat belt use among vehicle drivers on the Yangon-Bago Highway. The seat belt usage rate can be increased through the installation of educational signboards and enforcement measures.

- Helmet Use

Motorcyclists are particularly vulnerable in the event of a crash, with head and neck injuries being the leading cause of serious injury, disability, and fatalities. The most effective physical protection against traumatic brain injury is the use of a crash helmet. Therefore, in order to enhance rider safety, helmet safety signs should be installed in these high-risk areas to encourage consistent helmet use.

- Safety Education and Training

In populated areas, where motor vehicles, motorcycles, slow-moving vehicles, and pedestrians are densely present, ensuring safe and efficient traffic flow is essential. To achieve this, authorized traffic safety organizations should provide education and training programs for both drivers and pedestrians.

- Speed Management

To enhance road safety, vehicles on the Yangon–Bago Highway should be driven within the designated safe speed limits, particularly in high-risk zones. Speed control signs should be installed in advance of all bridge approaches to alert drivers and ensure speed reduction in these critical areas.

- Drink Driving

Road users who consume alcohol, even in relatively small amounts, are at increased risk of being involved in road traffic crashes. Alcohol impairs several functions critical to safe driving, including vision, judgment, and reaction time. Therefore, programs to reduce the incidence of drink driving should be implemented, including public awareness campaigns, enforcement of legal limits, and random breath testing.

- Prehospital Emergency Care

In high-risk zones, prehospital emergency care should be provided to individuals involved in road traffic crashes. Early medical intervention can be critical in saving lives and reducing the fatality rate caused by traffic accidents.

Moreover, modular impact cushions (CAMS) and regulatory or warning signs should be installed at blackspots and hazardous zones as emergency prevention measures. All regulatory traffic control devices must be supported by applicable laws, ordinances, or regulations. Fixed speed cameras should be installed in both urban and rural areas to monitor and ensure drivers comply with speed limits. Since the majority of accidents occur at night, existing highway lighting must be upgraded and improved to help reduce nighttime crashes.

The Yangon–Bago Highway, which passes through both urban and suburban areas, requires pedestrian crossing lights to be installed and enhanced to improve pedestrian safety. Curve warning signs must also be placed at appropriate locations before curves to reduce the risk of accidents at these critical points.

The guidance signs should provide drivers with clear, advance information about directions and highway conditions. The design features of these signs such as size, shape, colour, material, lighting or retro reflectivity, and contrast must work together to:

- Attract driver attention,
- Ensure the message is simple and clear,
- Provide legibility and appropriate placement for timely driver response,
- Promote uniformity and trust in the message being conveyed.

Warning signs should be placed at appropriate locations to alert drivers of potential hazards on the highway, helping to prevent accidents. Additionally, pavement markings serve multiple safety functions: they separate traffic lanes, guide bicyclists with designated paths, indicate proper stopping locations for signal detection, and offer advance information for turning or crossing manoeuvres. Therefore, faded pavement markings must be repainted and maintained to enhance overall road safety on the highway.

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